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Control Problems

Good afternoon. As you've gathered by now, IXO is a very mission-centric office. Dick has told you how we're going to extend sensor capabilities, how we're going to convert sensor data into targeting information, how we're going to help commanders control their forces, and how we're going to get information to everyone involved.

I'd like to talk a bit more about the control part of the problem—control of sensors that find targets, control of communications systems that move information, and control of weapons that neutralize targets.

Where do we start? Throughout history successful commanders have used surprise, maneuver, and firepower to achieve their objectives. Today, most strategists agree that we're going to reduce the role of firepower, which means that we're going to have to increase our capabilities to achieve surprise and maneuver.

One thing that's common to both surprise and maneuver is the notion of synchronization. We want to synchronize sensor coverage so that there are no gaps where enemies can hide. We want to synchronize communications so that information travels from sensors to weapons faster than enemies can evade. And we want to synchronize weapons so that we can surprise our enemies in a very lethal way.

Commanders in the ancient world knew the importance of these ideas, and used any technology that could help. I'm told that the Greeks invented an interesting device for all-weather, beyond-line-of-sight synchronization—Alexander used it in his Asia Minor campaigns.

At the end of a planning session, commanders dipped bits of cloth in die, tied them around their wrists, and then rode off to their units. When the material dried, all at the same time, the die changed color, and the commanders began their synchronized attacks.

Looking back, we could call this "Alexander's Rag Time band."

Somewhat more recently, electromechanical technology began to offer new devices to achieve synchronization and control: telegraphs, governors, and interlocks.

Along with the devices came some new mathematics and theories—differential equations, statistics, formal logic. And the interplay between devices and theories created a rich engineering experience that continues to influence us today.

IXO wants to build on this blend of theory and practice. We want to continuously acquire information, feed it to commanders so they can act rapidly and decisively, and decide what more they need. We have five basic principles that guide this view.

- First, humans are in charge. Military campaigns are some of the most complex intellectual structures constructed by mankind. No single human can understand all of a military operation. Yet commanders retain responsibility for everything that happens in their assigned areas. We'll strive to offload tasks from people, but we won't eliminate the human. And we won't constrain the commander's decision space. We'll enlarge it by helping them conceive, extend, and critique operations plans.

- Second, it's a closed-loop problem. We all know that "no plan survives contact with the enemy." The challenge of control and synchronization is not only to plan complex operations, but also to adjust and refine plans as events unfold. This is the hard part: anticipating what can go wrong, building contingency plans ahead of time, hedging against complete surprises, and deploying sensors to reduce the risk of surprises. We can change or extend a plan whenever new information or new objectives warrant it. We can take advantage of every unexpected opportunity that comes along.

- Third, it's a nonlinear and unstable control problem. We're not trying to stabilize a situation; we're deliberately taking action to change a situation. While the situation in the field is dynamic—that's where our ultimate objectives lie—it's also crucial to understand how our awareness of that situation is dynamic, too. We control the field situation through fire and maneuver. We control awareness through sensor placement, routing, and tasking. In IXO, we want to control both of them simultaneously: pre-positioning sensors to anticipate information needs for fire and maneuver and pre-positioning weapons to strike rapidly against newly-discovered targets.

Classical mathematics by itself doesn't supply adequate tools to synchronize sensing, communication, maneuver, and strike. We need new ideas or new combinations of ideas to solve these problems. I'm particularly optimistic about some recent unifying trends among the fields of planning, control, operations research, and fast simulation.

- Fourth, it's a collaborative problem. Eisenhower had more than 16,000 people on his staff at the end of World War II. Modern operations centers have less than a thousand, and we aspire to reduce forward footprints of command operations even further. But we don't want to build a super-processor that meticulously orchestrates everything in the battlespace. Many of the things we control will have highly talented people in them—we will engage those talents, not replace them. And even for automated platforms, we do not seek to build monolithic systems. Rather, we want to construct technical components that can be composed into varying systems, depending on the situation, mission, or even style of the command staff.

- Finally, theory and experimentation go together. We cannot evaluate, never mind develop, closed-loop battle management systems unless we can close the loop. And we need do this realistically. Of course, we cannot schedule real battles to suit our experimental needs, and so we need to simulate them. Many of our service partners are recognizing this need as well, and we will work with them to make sure that we build technology that will work reliably and well in the real world.

So what is it that we're trying to control? At least four things: platforms, sensors, tasks, and information.

Obviously we want to synchronize platforms. We want to guide smart bombs onto designated targets—regardless of how hard the bad guys try to evade us. We want to adjust positions of artillery or B-52s to anticipate time-critical calls for fire. We want to put communications repeaters in positions to maintain connectivity among sensors, commanders, and weapons. We want to synchronize Global Hawks doing wide-area search with low-altitude vehicles carrying ladar for precision target identification. We even want to guide robotic logistics vehicles to refuel remotely placed platforms.

But the challenge is toughest when individual platforms carry weapons, communications, sensors, and supplies—and that's the problem we're working.

We need to synchronize sensors, too. Most sensors can operate in several modes - different waveforms, different receiver characteristics, different signal processing. Some sensors work in combinations - bistatic, multistatic, or different array configurations. Electronically steerable arrays are agile and can even multiplex tasks; long-range cameras have complicated limits on dwell and slew times. Weather, climate, and foliage affect different sensors in different ways. We want to synchronize the operations of our diverse set of sensors so that we get the picture of the battlespace that best satisfies commanders' needs.

I mentioned earlier that military campaign plans are some of the most complex intellectual structures created by mankind. They consist of thousands of related tasks - airspace deconfliction, spectrum control, weaponeering, communications checks, and so on.

Unlike platforms and sensors, though, tasks are not physical objects, and so their synchronization is driven less by laws of physics than by procedures and training. We want to support commanders by helping them build plans, fleshing out details and checking for consistency. We do this at low levels—synchronizing operations on embedded flight control systems—and at high levels—synchronizing air and ground operations over difficult terrain—and everywhere in between.

Finally, we synchronize the flow of information between humans and machines. Knowing that a human might have to verify target ID, we want to set up a temporary, high-bandwidth data flow from a video sensor to a targeteer—but only for the critical periods of time. Knowing that a ground operation will take place in a remote valley, we want to pre-supply terrain and environmental information to the tools that will suggest sensor placements and maneuver routes. The challenge here, of course, is to describe the information needs and stores—of both humans and applications—in a form that allows us to infer what is needed, what is available, and how to connect the two.

So how will IXO confront these challenges? Let me suggest four directions.

- First, it's clear that the United States is going to aggressively extend the advantages we enjoy over our adversaries. One of these is automated platforms—robots by another name. IXO will not develop robots ourselves—we'll rely on our friends in the Tactical Technology Office to do that.

But we will address the problems of coordination and synchronization of highly automated platforms. So think about squads of robots—perhaps including many specialized kinds of robots: hunters and routers and suppliers and killers. And think about how we can get a squad of these things to perform the missions that Dick talked about—with only one human commander.

- Second, it's equally clear that our opponents surf the web and read our newspapers. So they get a pretty good sense of what we do well. And they will be highly motivated to avoid behaviors that we've defeated in the past. And they'll be fast learners.

So think about ways in which we can help our automated systems adapt equally rapidly—so that lessons we learn on the first day of a conflict can be instilled in our automated systems. Whether on-the-fly modeling, rapid knowledge elicitation, or guided discovery, we need ways to adapt our control systems to unexpected tactics discovered by our opponents. Or, alternatively, to the particular decision style of a commander and staff. Or, to the invention of a new tactical concept. Or, to the availability of a new sensor or weapon.

- Third, our advanced technology doesn't do much if it stays in the lab. But getting it into the field today is a massive software engineering task. Fielding large, monolithic command and control systems is slow, expensive, and often ineffective.

There are a lot of ideas about how to use agent-based computing and mark-up languages and brokering to assemble software systems on-the-fly, but they just don't have the depth, reliability, or maturity to be used to fight a war. We need ways to rapidly integrate a new algorithm or tool with existing databases, graphics, or applications. We need ways to positively guarantee that the new tool will not have unintended side effects. We need ways to validate the fact that a new tool is behaving as intended. We need ways to build trust and agility into command and control systems.

- Finally, no matter how good it is, control technology will not be used by the military unless it is comprehensible. But neither viewgraphs nor videos nor demonstrations can provide a deep, instinctive understanding of what a command and control tool can do. That takes frequent, intense experience.

So let's think about ways to create that experience. We have a new generation of warfighter quite comfortable with computers, but we still need to instill comfort in the tools we put on those computers. So modeling and simulation is one way to teach, train, and develop users of the technologies I've talked about today. And not just as individuals—but as teams and collaborators. In short, here are four crucial areas where we need new ideas:

- Squads of specialized robots under the control of one person

- Agile adaptation to new situations, either through real-time modeling, or through knowledge acquisition

- Rapid, trustworthy insertion of new tools into fielded systems

- Embedded collaborative training

And we want to do all of this in the context of precise control of sensors, communications, and weapons, in the air, and on the ground.